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A COMPARISON OF THE RATES OF EVAPORATION IN CERTAIN ASSOCIATIONS IN CENTRAL ILLINOIS[1]

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(WITH SIX FIGURES)

During the session of the Biological Summer School of the University of Illinois, held at Havana, Ill., during June and July 1910, a series of measurements of the relative rates of evaporation within certain plant associations was made. In view of the growing interest in the study of evaporation and its relation to vegetation, the results obtained are here presented.

The greater part of our knowledge of evaporation in relation to vegetation has been given to us through the work of LIVINGSTON and TRANSEAU. One of the most suggestive papers is that of TRANSEAU,[2] in which he determined the relative rates of evaporation for a number of habitats about Cold Spring Harbor, Long Island, N.Y. He has summarized his results in a diagram which clearly shows the marked difference in the amount of evaporation in areas close to each other but differently vegetated. While TRANSEAU worked with habitats, as he expresses it, in the work at Havana certain definite plant associations were selected in which to determine the rate of evaporation.

Havana is located on the east bank of the Illinois River in central Illinois. The climate may be briefly characterized by the following statements: an average temperature during June and July of about 24° C., with warm nights and hot days, and a yearly rainfall of about 90 cm., of which considerably more than half falls during the growing season. Strong winds are frequent, as is usually the case in the central states. Except on the alluvial river bottoms, the soil of the area is sandy with a slight admixture of humus. Most of the area was originally occupied by associations of the Prairie

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[1] Contribution no. 125 from the Botanical Laboratory of the University of Michigan.

[2] TRANSEAU, E. N., The relation of plant societies to evaporation. BOT. GAZ. 45:217–231. 1908.

Province, but the climatic dominance of the associations of the Deciduous Forest Province is now gradually asserting itself wherever conditions are not interfered with by man. The climax type of vegetation for this part of Illinois, the *Acer saccharum* association, does not occur in the immediate vicinity, although it is present on clay and loess bluffs on the opposite side of the river.

The principal object of the investigation was the determination of the relative amounts of evaporation in certain well marked associations whose successional relations were clearly evident, in order to correlate the phenomena of succession and evaporation. A minor object was the comparison of evaporation in two areas with the same dominant vegetation, but with different secondary species. The results obtained were even more striking than had been anticipated.

The atmometers used were porous clay tubes, of the model recommended by TRANSEAU, about 30 cm. long and 2 cm. in diameter. The tubes were inserted into bottles through holes in the corks, and were then sealed with red sealing wax to prevent the entrance of rainwater and the loss of water by evaporation. A small S-shaped groove on the side of the cork permitted the equalization of the atmospheric pressure within the bottle. Reading the instruments immediately before and after heavy rains indicated that the arrangement was water-tight. The instruments were filled with distilled water, and to each 250 cc. was added one drop of formalin to prevent the growth of organisms. According to LIVINGSTON[3] the addition of formalin is not recommended in studies of absolute values of evaporation. Since this study was concerned with relative values only, and since all the instruments were treated alike, the slight effect of formalin is without significance. The instruments were set up and allowed to run for three weeks before the field records were taken, to insure the thorough saturation of the clay tubes. Each bottle was marked just below the cork, and was refilled by pouring in water from a graduate up to the mark. The readings were estimated to be correct within 0.5 cc. All the instruments were exposed together in the open air for 93 hours for standardization. Eleven instruments were then exposed in the association selected, while a twelfth, arbitrarily chosen as the standard, remained in its original location. Readings in the field were continued for 23 days, and then all the instruments were again standardized for 93 hours in the original location. Readings of the standard were taken daily, while those in the field were read at intervals of one to four days. Since the purpose of the work called for the total amount of evaporation rather than the daily fluctuations, the observed amounts of evaporation from each instrument were added, and the total amounts reduced to terms of the standard instrument by multiplying by the factor obtained in the two standardizations. The results are therefore directly comparable, and have been plotted in the accompanying diagram (fig. 6). Since they are not absolute values, they have been expressed in terms of the evaporation from the standard instrument, which is here designated 1.00.

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[3] Plant World **13**:118. 1910.

Two atmometers were located in each of five distinct associations, and one other was set up on the sandy beach of Quiver Lake. Four of the associations were in sandy soil, and their vegetation has been described in detail by GLEASON.[4] A brief description of the vegetation and the successional relations of the associations, however, may be given here.

The standard.—During standardization the atmometers were placed on the ground in the Chautauqua Park athletic field, and the standard instrument was kept there during the whole period of observation. This field was formed by leveling the sandy ground after cutting off the mixed forest association which covered it. It was bordered by a cultivated field on the east, and was surrounded on the other three sides by forest at a distance of 50–100 m. from the atmometers. The field was partly covered by weeds, of which the following were the most abundant: *Erigeron canadensis*, *Mollugo verticillata*, *Eragrostis Purshii*, *Erigeron divaricatus*, *Verbena stricta*, *Erigeron annuus*, *Cenchrus carolinianus*, and a few other grasses. The atmometers were placed in the center of an area cleared of the taller weeds for a radius of about one meter (fig. 1).

The river bank.—One atmometer was maintained on the sandy eastern bank of Quiver Lake, at a height which corresponds to a reading of 15 feet above the zero of the Havana gauge, located about 2.5 km. south. The lake has a continuous connection with the Illinois River, forming an expanse of water about 400 m. wide. During the course of the experiment the river fell from 12 to 7.8 feet on the Havana gauge. The location of the atmometer was selected to show the evaporation from an open surface near the water. The ground is sandy and for the most part without vegetation because of its regular inundation during high water in the river. The plants that occur along the beach are mostly sand plants, such as *Sporobolus cryptandrus*, *Cenchrus carolinianus*, and *Opuntia Rafinesquii*. There are some relics from the mixed forest above, as *Clematis Pitcheri*, and numerous xerophytic weeds, as *Melilotus alba*. A few trees still grow at the water's edge, but most of the original shore vegetation has succumbed to the effect of the higher average level of the water since the opening of the Chicago

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[4] GLEASON, H. A., The vegetation of the inland sand deposits of Illinois. Bull. Ill. State Lab. Nat. Hist. 9:23–174. *figs. 6. pls. 20.* 1910.

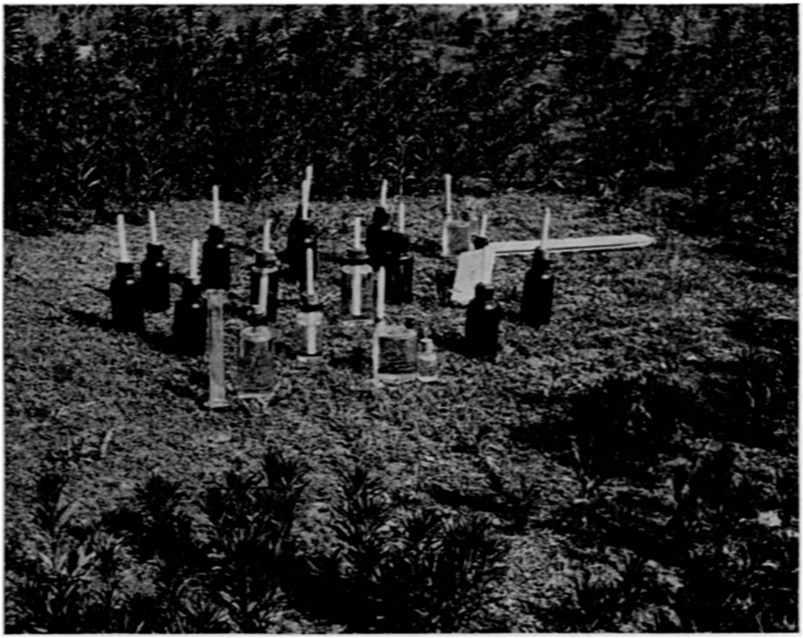

Fig. 1.—Atmometers in process of standardization, June 22, 1910; photograph by F. C. Gates.

Drainage Canal. The evaporation from this atmometer was very pronounced during the day, but was much lower at night. Sometimes virtually no nocturnal evaporation was indicated, while on the athletic field, about 200 m. inland and separated from the river by a forested dune, the evaporation was quite noticeable.

The bottom-lands.—The bottom-lands immediately across the river show plainly the results of the persistent high water during the last few years. The low banks and islands between the numerous lakes are still mostly covered with trees, but they are gradually being killed. A marginal zone of *Salix longifolia* represents the *Salix-Cephalanthus* association, while in the interior or highest parts of the islands a few maples, *Acer saccharinum*, occur, showing the former presence of the *Ulmus-Acer* association. A few pecan trees, *Carya illinoensis*, are present, but other tree species are rare. The ground is submerged during the greater part of the year. If emergence occurs during the summer, the surface is in a few weeks thickly covered with a growth of weeds, of which the most abundant are *Xanthium commune*, species of *Aster*, and other composites, and with numerous seedlings of willow and maple, none of which, however, survives the following winter. One atmometer was placed in a large rotten willow stump, about 6 m. from the river bank and about 2 m. above the surface of the mud. When first located, the station was covered half a meter deep with water. Another instrument was stationed in a maple stump, 1.7 m. above the mud, and about 8 m. from the river (fig. 2). Since the maple leaves were more nearly confined to the upper parts of the trees, while the willows were leafy almost to the ground, the better circulation of air permitted a greater evaporation under the maple trees.

The bunch-grass association.—Of the several consocies of the bunch-grass association occurring in the region, two adjacent ones were selected, characterized respectively by *Eragrostis trichodes* and *Leptoloma cognatum*. The former of these is the more stable, and consists chiefly of well defined bunches of *Eragrostis* spaced about 2–4 dm. apart. Other less conspicuous or less abundant grasses occur also, particularly *Andropogon furcatus*, *Leptoloma cognatum*, *Sorghastrum nutans*, and *Paspalum setaceum*, with a few plants of other species. Scattered among the grasses are plants of several secondary species which fill the spaces between the bunches and give the area the appearance of a closed association. The more prominent of these are *Lespedeza capitata*, *Opuntia Rafinesquii*, *Crotonopsis linearis*, *Ambrosia psilostachya*, *Oenothera rhombipetala*, *Lepidium virginicum*, *Krigia caroliniana*, *Cyperus Schweinitzii*, *Specularia perfoliata*, *Croton glandulosus*, *Erigeron canadensis*, *Commelina virginica*, *Monarda punctata*, *Callirhoe triangulata*, *Carex Muhlenbergii*, and *Erigeron strigosus*.

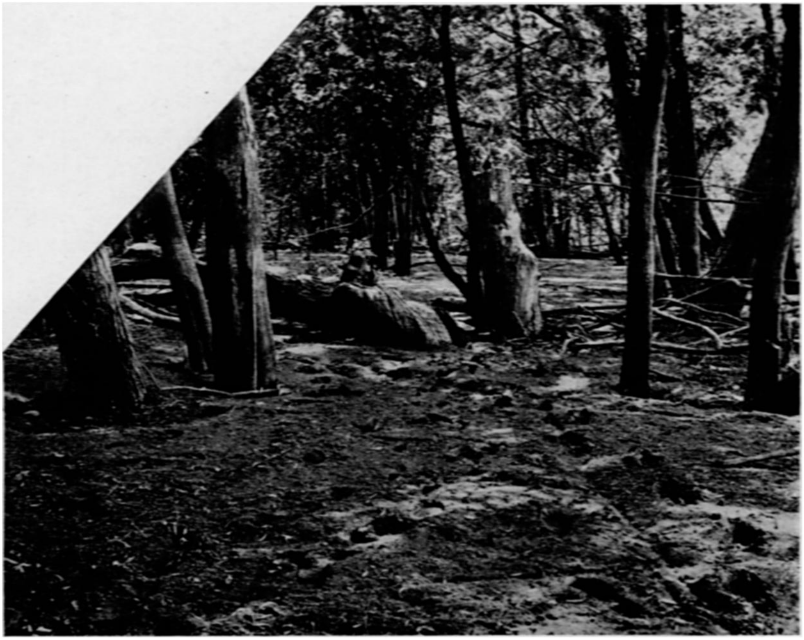

FIG. 2.—The center of a willow island, showing atmometer no. 1 on a maple stump, July 9, 1910; photograph by F. C. GATES.

The *Leptoloma* consocies, which is very abundantly represented in this region, is a less stable type of bunch-grass. The dominant species, *Leptoloma cognatum*, does not form bunches as well defined as those of *Eragrostis trichodes*, but with its spreading habit and irregular bunches occupies a larger proportion of the area. With it are associated a few other grasses, especially *Panicum pseudo-*

pubescens, *Cenchrus carolinianus*, *Sporobolus cryptandrus*, and *Bouteloua hirsuta*, with less of *Paspalum setaceum* and *Andropogon scoparius*. The secondary species are not numerous, but a few species are so conspicuous at certain seasons of the year that they make distinct aspects. The *Oenothera rhombipetala* aspect dominated during the period in which this experiment was conducted. The most important secondary species are *Opuntia Rafinesquii*, *Lepidium virginicum*, *Ambrosia psilostachya*, *Tephrosia virginiana*, *Chrysopsis villosa*, *Monarda punctata*, *Croton glandulosus*, *Oenothera rhombipetala*, *Cyperus Schweinitzii*, *Tradescantia reflexa*, *Specularia perfoliata*, *Lithospermum Gmelini*, *Petalostemum purpureum*, *Draba caroliniana*, *Euphorbia Geyeri*, *Lespedeza capitata*, *Krigia caroliniana*, *Cassia Chamaecrista*, *Pentstemon hirsutus*, *Antennaria* sp., and *Aster sericeus*. The atmometers in these two consocies were about 15 m. apart.

The blowouts.—The blowouts are excavations in the mobile sand caused by the action of wind. In this region nearly all of them are surrounded by the bunch-grass prairie. The sand is virtually free from vegetation except for a few species, such as *Acerates viridiflora*, var. *lanceolata*, *Cristatella Jamesii*, and *Aristida tuberculosa*, which find here their preferred habitat. The dry surface layers of the sand are blown by every wind, and become very hot on sunny days. One atmometer was placed in the bottom of the complex known as the Devil's Hole, 3 km. east of Havana, and another half-way up its lee slope toward the east (fig. 3).

The Quercus velutina association.—The first forest association to appear on the sand in this region is characterized by *Quercus velutina* and *Q. marilandica*. Of the two, the former is usually more abundant and better developed. In typical situations other species of trees are seldom present. In general, *Q. marilandica* tends to occupy the poorer soil, and is more frequently the first to appear on cleared or lumbered land, but *Q. velutina* seems to be more persistent and better able to hold its own. The presence of trees of *Carya cordiformis* may indicate an incipient succession of the mixed forest association. Actual count of the trees in the vicinity of one atmometer showed that 57 per cent of the old trees were *Q. velutina*, 42 per cent *Q. marilandica*, and 1 per cent *Carya* *cordiformis*. In the typical areas of this association, there are neither vines nor shrubs, with the exception of some shrubs remaining as relics from the prairie, even though the seeds are already present in the sand beneath the trees. The presence of *Psedera quinquefolia* and other vines in some places is accordingly considered an indication of the approaching succession of the mixed forest association. The shrubby growth consists largely of the young trees of the dominant species, together with *Rhus canadensis*, var. *illinoensis*, and *Ceanothus americanus*, relics from the bunch-grass. The herbaceous vegetation but sparsely covers the ground, although the number of species represented is usually large. The most common and typical are *Tradescantia reflexa*, *Amorpha canescens*, *Euphorbia corollata*, *Smilacina stellata*, *Phlox bifida*, *Verbascum Thapsus*, *Monarda fistulosa*, *Lithospermum Gmelini*, *Aster azureus*, *Rudbeckia hirta*, *Lespedeza capitata*, *Pentstemon hirsutus*, *Asclepias tuberosa*, *Tephrosia virginiana*, and *Rosa humilis*. The soil is sand

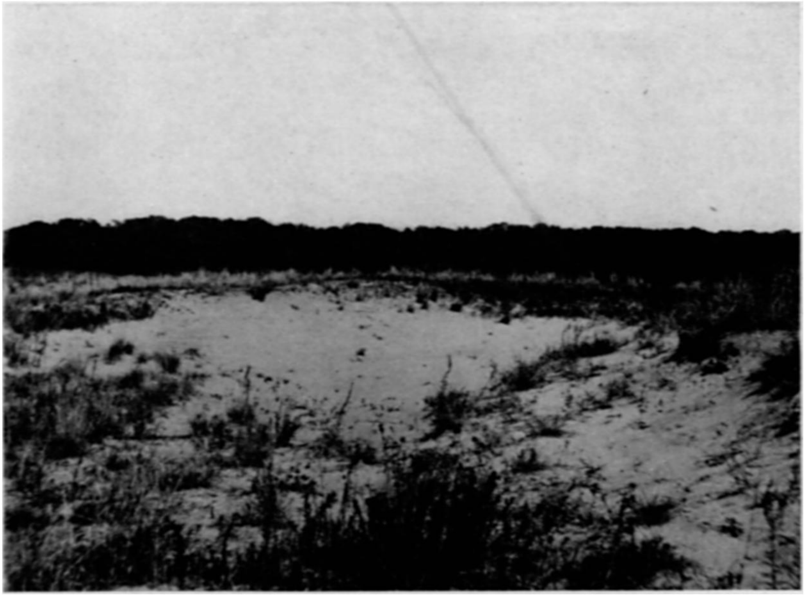

FIG. 3.—A blowout near the station of atmometer no. 8, July 1910; photograph by ARTHUR G. VESTAL.

to within a few centimeters of the surface, which is covered with a layer of dead but undecayed leaves. Two atmometers were maintained in woods of this type about 500 m. from the bunchgrass and blowouts. One of them was in a typical area of the vegetation (fig. 4), and the other in an area in which there were numerous young trees of *Carya cordiformis*.

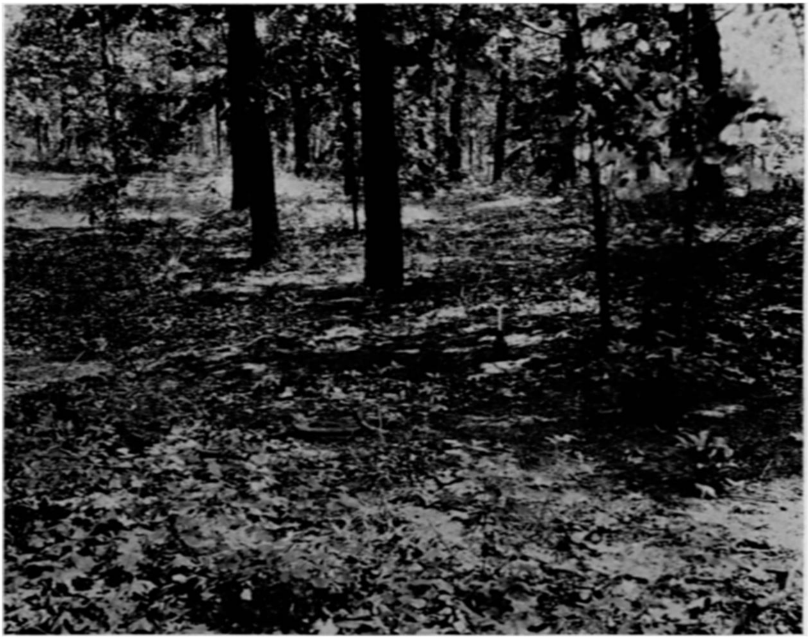

FIG. 4.—Interior of *Quercus velutina* association, showing atmometer no. 7, July 9, 1910; photograph by F. C. GATES.

The mixed forest association.—In the mixed forest more than half of the trees are of species typical of the *Quercus velutina* association which has preceded it. In this particular area, the oldest trees are without exception *Quercus velutina*, while near the edge there are some large *Q. marilandica*. There are also numerous young trees of *Carya cordiformis*, which are nearly as large as the more slowly growing oaks. Scattered among the individuals of these three species are a few trees of *Gymnocladus dioica* and *Celtis occidentalis*, the latter only near the margin. An actual count of the trees near the atmometer gave the following results: *Carya cordiformis*, 62.5 per cent; *Quercus marilandica*, 19.2 per cent; *Q. velutina*, 14.3 per cent; *Celtis occidentalis*, *Gymnocladus dioica*, and *Quercus rubra*, each 1 per cent. The proportion of the young trees, however, is very different. Between 80 and 90 per cent of them are *Carya cordiformis*. They dominate in every clearing, although occasionally they are accompanied by a few young trees of *Quercus velutina*. Young trees of *Q. marilandica* are not at all plentiful and occur only at the edges. The luxuriance of the growth of vines is the most prominent feature of the change from the *Quercus velutina* association. Nearly everywhere in the mixed forest vines are the conspicuous ground cover. This is never true of the typical *Quercus velutina* association. Most prominent of these is *Psedera quinquefolia*, which not only carpets the ground with green, but also climbs to a considerable height. More noticeable as climbers, however, are *Celastrus scandens* and *Vitis vulpina*. Shrubs are prominent only near the margin of the association, although a few species are scattered throughout. The commoner species of the herbaceous vegetation are *Scrophularia leporella*, *Anychia canadensis*, *Parietaria pennsylvanica*, *Hedeoma pulegioides*, *Asclepias phytolaccoides*, *Galium circaezans*, *Aquilegia canadensis*, *Galium pilosum*, *Silene stellata*, and *Cacalia atriplicifolia*. Two atmometers were maintained in this association. One was located near the margin of the grove, while the other (fig. 5) was near the center.

From an inspection of the data given in the diagram it is seen that the bunch-grass, the blowout, the *Quercus velutina*, and the mixed forest associations all show noticeably different amounts of evaporation. The instruments in these associations were located within half a kilometer of each other, in a region of comparatively uniform topography. The variation in the physical factors of the environment is not sufficient to explain the wide variation in the amount of evaporation. Accordingly the vegetation, which is the most variable factor of the environment, appears to be the essential factor in determining the evaporation rate. This, however, is accomplished indirectly, since vegetation influences evaporation chiefly through the control or modification of the wind, the temperature, and the humidity, all of which affect the evaporation directly. The diagram shows also that those associations which stand high genetically have a lower evaporation rate than those genetically lower in the successional series.

This relation between succession and evaporation is best shown in the sand dune habitats, where four sets of atmometers were maintained. The original vegetation there is the bunch-grass association, but under certain conditions portions of the association may be destroyed by wind action, resulting in open areas of bare sand, the blowouts. The present blowouts are all of secondary origin, but their environment and vegetation probably represent the primitive condition of the region, shortly after its emergence from the glacial Illinois River. In these blowouts the highest evaporation occurs. The blowout is eventually revegetated by bunch-grass, during which process two or more consocies of the bunch-grass association appear. The *Leptoloma cognatum* consocies

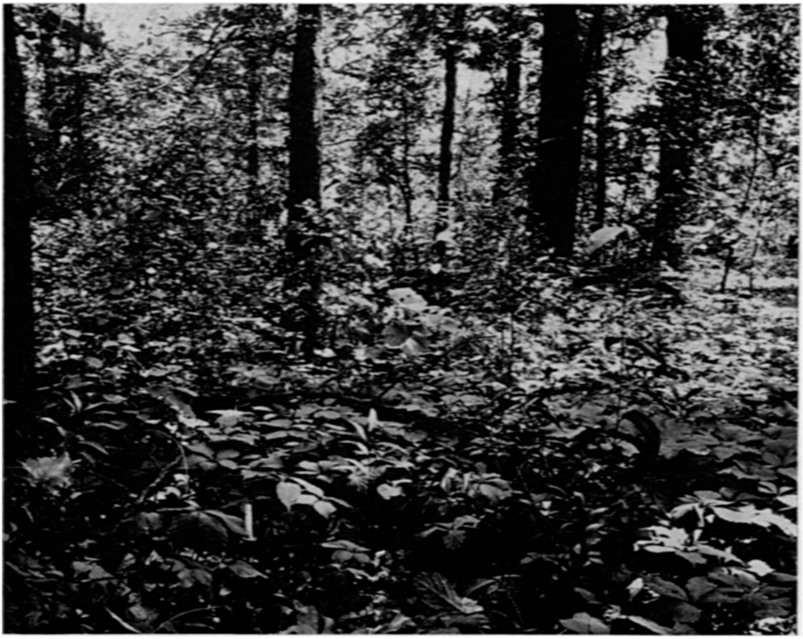

FIG. 5.—Interior of the mixed forest association, showing atmometer no. 11, July 9, 1910; photograph by F. C. GATES.

is usually the earliest one to develop, and later is followed by the *Eragrostis trichodes* consocies. The latter, representing the higher development of the association, has an evaporation rate which is 88 per cent of the lower type. In both cases the amount of evaporation from the bunch-grass is lower than that from the blowout, although the four atmometers were less than 100 m. apart.

The difference in the rate of evaporation in the bunch-grass and *Quercus velutina* associations is much more marked. Young oak trees in different stages of development are present in the former association, clearly demonstrating that they are capable of withstanding the relatively high prairie rate of evaporation. With their growth to maturity, and the consequent succession of the bunch-grass by the forest, the evaporation beneath them is steadily diminished, until it becomes about 55 per cent of that of the normal bunch-grass. Atmometer no. 7 was placed in a typical part of the *Quercus velutina* association (fig. 4).

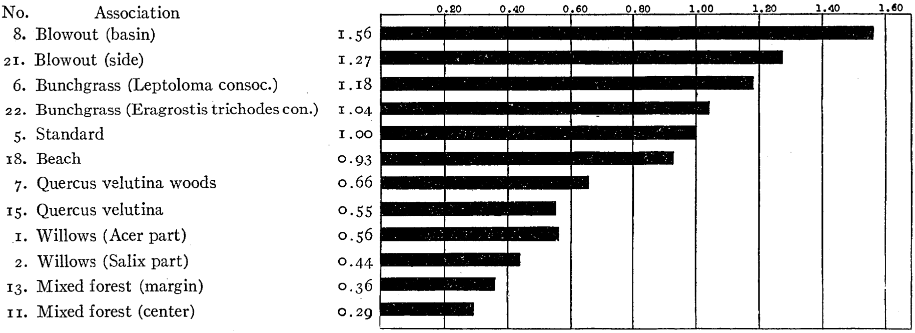

FIG. 6.—Diagram showing relative amounts of evaporation in the different stations.

With the increase in the age and density of the forest cover, the evaporation beneath it is still further reduced. Eventually the succession of the mixed forest association begins, and the first indication is usually shown by the presence of *Psedera quinquefolia* and *Celastrus scandens*. Atmometer no. 15 was located in such a place, and the diagram shows a reduction in the rate of evaporation from 0.66 to 0.55, in terms of the standard. The reduction is still greater in the typical mixed forest, represented by instruments

11 and 13, the latter of which was placed near the border of the association, while the former was in the center. With the establishment of the mixed forest association the sand area reaches the present culmination of the successional series. Throughout this series the amount of evaporation has steadily decreased, reaching its lowest rate in the association genetically highest.

Actual observation shows that the succession of the bunch-grass by the *Quercus velutina* association begins in the normal association, where the rate of evaporation is high. It also shows that members of the mixed forest association appear in the *Quercus velutina* association while the evaporation rate there is still relatively high. In both cases the development of the association reduces the evaporation. Succession, therefore, does not depend upon evaporation; it is a cause rather than an effect.

The other records shown in the diagram are not to be placed in this genetic series. Sufficient instruments were not at hand, nor does this particular locality give the opportunity for investigation in the series of associations beginning with the open water and ending with bottom-land forests. Nevertheless, one or two points are brought out, notably that the evaporation on the open sand of the river beach is not nearly so great as that from the open sand of a blowout. The river is here a most important factor, tending to reduce the extremes of temperature during the day, and maintaining a relatively high humidity during the night. Evaporation from the willow and maple islands was greater than from the mixed forest, although the latter grew in dry upland sand, and the former in mud, during part of the experiment covered and at all times surrounded by large bodies of water. This is simply another instance indicating that the vegetation is of greater importance than the physical environment in controlling evaporation.

Conclusions and summary

1. Since proper conditions for maintaining an absolute standard were lacking, the results were all calculated on the basis of one instrument arbitrarily chosen as a standard, and are represented in relative terms only.

2. Differences in the amount of evaporation in various associations are due chiefly to the nature of the vegetation, which by its size and density controls the evaporation beneath it.

3. The observations indicate that successions between associations are not caused by any conditions of evaporation.

4. The more primitive associations have the higher rates of evaporation, while those most nearly like the climax type have the lowest rates. This is true not only for the forest associations, in which low evaporation is expected, but also for the prairie associations, which are correlated with an arid climate and consequently high climatic evaporation.

The standardization and field observation of the atmometers and the evaluation of the relative rates of evaporation were managed entirely by the junior author; for all other statements both authors are responsible.

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